Advances in Swine Nutrition to Address Nutrient Management Issues

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Table of Contents

1. Background
2. Determining Mineral Balance
3. Lowering N and P Excretion through Nutrition
4. Lowering N and P Excretion through Genetics
5. Conclusions
6. References
7. For More Information

Background

This review discusses the general principles of nutrition as it relates to nutrient management and focuses on ways of manipulating the pig's diet to reduce the excretion of nutrients in pig manure. The nutrients of prime concern are copper (**Cu**), zinc (**Zn**), nitrogen (**N**) and phosphorus (**P**).

Copper and Zinc

In general, Cu and Zn in pig diets are much higher than the minimum requirements for normal performance (i.e.: 5-25 ppm Cu and 50-125 ppm Zn for the various classes of swine). This is because these minerals act as growth promotants when included at levels much higher than minimum requirements. In Canada, the federal Feeds Act limits the maximum level of Cu and Zn in the diet to 125 ppm and 500 ppm respectively, but in the US, much higher levels are common. In some countries, like the Netherlands, growth promoting levels of Cu and Zn are no longer allowed in finisher pig diets due to the impact on the environment. As long as minimum requirement levels of Cu and Zn are maintained, the excretion of these minerals in pig manure is not a concern; the focus then switches to P and N excretion.

Bioavailability of N and P

Knowledge about the bioavailability of N and P in feed ingredients can help to reduce these minerals in swine manure without affecting performance. **Table 1** shows the bioavailability of N and P in a wide variety of feed ingredients.

Table 1: Bioavailability of nitrogen and phosphorus in feed ingredients for pigs

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Feedstuff	Bioavailability		Feedstuff	Bioavailability	
	P* (%)	N** (%)		P* (%)	N** (%)
Corn	14	78	Canola meal	21	78
Oats	22	76	Soybean meal, dehulled	23	90
Barley	30	79	Soybean meal , 44% protein	31	89
Triticale	46	81	Feather meal	31	67
Wheat	50	81	Meat and bone meal	90	80
Oat groats	13	79	Dried skim milk	91	93
Corn gluten meal	15	80	Blood meal	92	94
Rice bran	25	78	Fish meal	94	95
Wheat bran	29	71	Dried whey	97	87
Brewers grains	34	82	Steamed bone meal	85	-
Wheat middlings	41	89	Defluorinated phosphate	90	-
Corn gluten feed	59	66	Monocalcium phosphate	100	-
Distillers grains	77	75	Dicalcium phosphate	100	-
Alfalfa meal	100	56			

*bioavailability relative to the availability of P in monosodium or monocalcium phosphate which are given a value of 100

**true ileal digestibility of lysine

Source: National Research Council, 1998.

Table 2 shows the N and P balance for *typical* grower-finisher pigs fed *typical* diets. The bottom line shows that approximately two-thirds of N and P intake is excreted in manure. Starter pigs are slightly more efficient while sows are less efficient. However, since grower-finisher pigs produce the majority of the manure on a typical farrow-to-finish operation, *typical* farm values would be similar to the values shown. This extremely low level of efficiency leaves room for decreasing N and P excretion by improving the efficiency of retention in the pig (deLange, 1997).

Table 2: Typical N and P balances (kg/animal) in grower-finisher pigs (25-106 kg)

Parameter	Nitrogen (N)	Phosphorus(P)
Dietary level (%)	16.7*	0.52
Intake (kg/pig)	6.36	1.23
Retention (kg/pig)	1.88	0.40
Excretion (kg/pig)	4.48	0.83
Excretion (% of Intake)	71.5	67.5

*crude protein (Nx6.25) rather the N levels

Source: Jongbloed, 1991

| Top of Page |

Determining Mineral Balance

Variation in the amount of minerals excreted with manure can be attributed to various animal and feed factors. These include:

- feed usage, the level and digestibility of AAs and P in the various diets
- the minimum amounts of N and P used by the pig's body (maintenance requirements)
- the (marginal) inefficiency of utilizing AA and P that are supplied over maintenance but below maximum N and P retention in the pig's body
- the balance of AAs supplied in the diet vs. the balance of AAs required
- the rate of N and P retention in the pig's body

A simple computer program has been developed, with support from Ontario Pork, to accurately predict the excretion in manure of the minerals of concern (N, P, K) in environmental pollution (deLange and Birkett, 1997). The computer program calculates N, P and K excretion in pig manure from the difference between the amounts of N, P, and K that are fed to the animals (based on amounts of various feeds used and the N, P, and K content in the various feeds) and the amounts of N, P, and K removed from the farm in animals (based on the number of pigs in each category that are removed from the farm and N, P and K content in these pigs). This is similar to the system used in the Netherlands, but adjusted to Ontario conditions.

| Top of Page |

Lowering N and P Excretion through Nutrition

The three most expensive components of a swine ration are N (an important component of protein and amino acids), P and energy. Nitrogen and phosphorus are also the most important contributors to pollution from swine manure, so it is important to maximize the efficiency with which these nutrients are used. Excretion of N and P in swine manure can be substantially reduced by a number of strategies.

Improving Performance Potential

Improved productivity is the most obvious strategy for reducing nutrient excretion. In general, a better feed conversion ratio leads to a lower excretion of N and

minerals. An improvement in feed conversion of 0.25 units would reduce nitrogen excretion by 5 to 10% (Coffey, 1996). Over the past 20 years, the feed efficiency of pigs growing from 25 kg to market weight has gradually decreased from approximately 4.0 to less than 2.85 in top-producing herds.

Pigs with a higher protein deposition rate have a better feed conversion ratio as a result of a higher lean meat percentage (Jongbloed and Henkens, 1996). Feed additives which promote growth may also reduce excretion of N and P as a result of a better feed conversion compared to non-supplemented feeds. In addition, improvement in the herd health status, or in the thermal environment to which pigs are exposed will lead to improvements in feed efficiency and thus reductions in mineral excretion. Keller (1980) estimated that converting to a specific-pathogen-free herd health status can improve feed efficiency by as much as 10% and, as a result, decrease N excretion by 10%.

Enhancing Nutrient Availability

Enzymes for Non-Starch Polysaccharides

The carbohydrate fraction of feed ingredients consist of starch, sugar and non-starch polysaccharides (**NSPs**) like cellulose, hemicellulose, pectins and oligosaccharides. These NSPs are resistant to digestive enzymes but digestibility of these fibrous feeds can be improved by treatment with enzymes that are capable of hydrolyzing the NSP to monosaccharides. Currently, data showing significant improvement in pigs are very scarce (Jongbloed and Henkens, 1996) but there is potential that these enzymes could further reduce N and P excretion for pigs.

Reducing Anti-Nutritional Factors

Most legume seeds, such as soybeans, contain different anti-nutritional factors (**ANFs**), i.e. protease inhibitors, lectins, tannins, and amylase inhibitors. Digestibility and absorption of protein is compromised when these ANFs are present. Elimination of ANFs from the feed and better processing conditions can improve N utilization in pigs which will reduce N excretion.

Phytase

The most important ANF in swine nutrition, as it relates to nutrient management, is phytate. The major ingredients in pig diets are seeds (cereal grains) or products from seeds (oilseed meal and grain byproducts). However, 60-80% of the P in these feedstuffs is present in the form of phytate, a compound that pigs do not use well. Bioavailability estimates of P in corn and soybean meal for pigs range from 10-30% (Kornegay, 1996). This low availability of phytate P poses two problems for producers:

1. the need to add inorganic P supplements to diets, and
2. the excretion of large amounts of P in the manure.

Phytate P must be hydrolyzed by an enzyme, phytase, into inorganic P before it can be used by pigs. Four sources of phytases have the potential to degrade phytate within the digestive tract of pigs:

- intestinal phytase in digestive secretions
- endogenous phytase present in some feed ingredients
- phytase originating from resident bacteria
- phytase produced by exogenous microorganisms

Unfortunately, all of these potential sources have proven to have negligible phytase activity for improving phytate availability in nonruminant animals

(Kornegay, 1996).

Phytase activity has been reported in a wide range of seeds but it varies greatly among species of plants. With the exception of wheat and rye and their hybrid, triticale, most contain very low phytase activity (Kornegay, 1996). The majority of phytase activity in wheat, rye and triticale is in the bran. Phytase activity in corn and soybean meal is so low that it is of no practical importance.

Phytate also impairs the bioavailability of minerals other than P. Minerals that may be bound by phytate include Zn, Cu, Mn, Fe, Mg, Ca and Cr. Hydrolysis by phytase should release the minerals that are bound, allowing for improved absorption of Ca, Mg, Zn and Fe in pigs (Kornegay, 1996).

It is well known that P utilization by animals is influenced by dietary Ca and vitamin D. Adding microbial phytase to diets containing high levels of phytate P will enhance Ca, P and Zn availability and can result in lower levels of these minerals being excreted. The dietary level of Ca or the Ca:phytate ratio and the Ca:P ratio are important factors that influence the release and utilization of P. Ratios of Ca and P above 1.4:1 have an adverse effect on the release of P from phytase, whereas added vitamin D3 has a positive effect. Decreasing the Ca to P ratio from 2.0:1 to 1.4:1 or 1.1:1 has been shown to improve phytase efficiency in the range of 5-12% (Kornegay, 1996).

Research has proven that phytase can improve P digestibility. As a result, the total P levels in the diet are reduced, the efficiency of retention improved and excretion of P into the environment is decreased (Table 3). In addition, feeds supplemented with phytase for grower-finisher pigs and for pregnant sows may need little or no supplementary feed phosphate. Currently, the addition of phytase does not appear to add more cost to the diet because it is offset by the savings associated with reducing P and Ca in the diet.

Table 3: Effect of added phytase on P digestibility in growing pigs fed corn-soybean meal based diets

Parameter	*Control*	*Control + 1000 phytase units/kg*
Total P (g/kg diet)	3.3	3.3
P digestibility (%)	20	46
Digestible P (g/kg diet)	0.66	1.52

Source: Simons et al. 1990.

The excretion of P can be reduced by 25-50% with the addition of 200-1000 units of phytase. Based on available information (Kornegay, 1996), a 109 kg pig consuming 318 kg of feed from 18 kg to market:

- would eat 1.43 kg of P if fed NRC recommended levels (4.5 g P/kg diet)
  - = would excrete about 0.71 kg of P
- would eat at least 1.11 kg of P if phytase is added to the diet
  - = would excrete about 0.56 kg of P or less
- would eat 1.75 kg of P if higher than NRC levels (5.5 g P/kg diet)
  - = would excrete at least 0.88 kg of P

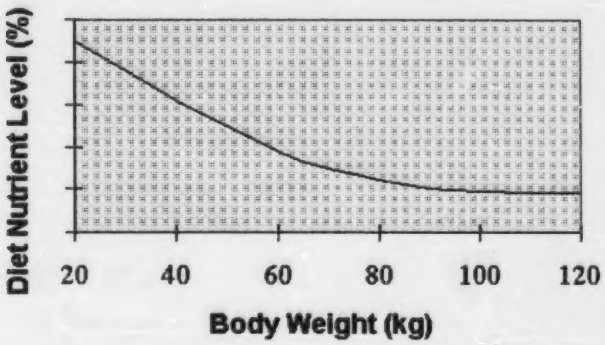
Translate that to annual hog marketing figures and it means that, with 5 million pigs in Ontario (average P intake of 1.59 kg/pig), a 30% reduction in P excretion would represent about 2.4 million kg less P excreted annually.

Matching Supply of Nutrients to Requirements

Phase Feeding

As the liveweight of a pig increases from 30 to 110 kg, the concentration of amino acids (**AAs**) and P in the feed decreases. So, the introduction of one or more additional feed(s) , known as phase feeding, for grower-finisher pigs will help balance AAs and digestible P in the diet to the requirements of the animal so less N and P is excreted (See Figure 1).

Figure 1: Change in required dietary nutrient levels in relation to body weight



Source: Swine Nutrition Guide, 2nd Edition, 1995.

When diets are precisely formulated to meet the protein and amino acid requirements of pigs, nitrogen excretion is reduced due to decreased dietary excess and improved utilization of nutrients. Lenis (1989) calculated the reduction in nitrogen excretion that would result from changing from one feed system that is common in Europe to a 2-phase system (Table 4). Meeting the N needs more precisely would reduce N in manure by 13%.

Table 4: The effect of phase feeding on nitrogen excretion in grower-finisher pigs

Item	*One Feed*	*Two Feeds*		
		Grower	*Finisher*	*Overall*
Protein (%)	16	16.5	14	-
Feed:Gain	3.0	2.5	3.3	-
Feed Intake (kg)	210	75	132	207
N Intake (kg)	5.38	1.98	2.95	4.93
N excreted (kg)	3.48	1.16	1.86	3.02
N excreted (%)	65	58	63	61
N retention (kg)	1.9	0.82	1.09	1.91

Source: Lenis, 1989.

A slightly larger reduction in N and P excretion can be achieved for growing pigs by mixing a feed rich in protein and minerals with a feed that has a low concentration of protein and minerals in a changing ratio during the growing period. This mixing system, referred to as multiphase feeding, works with a computerized mechanical feeding system. A feeding strategy is developed once a good fit of energy, protein, and mineral supply has been established based on pig potential, stage of production, production objective and environmental constraints (Jongbloed and Henkens, 1996).

Split Sex Feeding

Feeding barrows and gilts separately, known as split sex feeding, can also decrease excretion of N and P. It is well known that barrows eat more feed, grow faster, are less feed efficient and yield lower carcass lean than gilts. Although there is little difference between barrows and gilts up to 25 kg, differences in feed intake and growth rate may be as high as 15% during the finisher phase. Because they eat less feed and have a higher lean growth rate, gilts require higher levels of AAs and other nutrients than barrows. Different diets can be fed to more closely match the nutrient requirements of the separate sexes while limiting excesses and reducing excretion.

Individual Feeding

Required concentrations of N and P in feed for breeding sows are much lower during pregnancy than during lactation. The use of separate diets for dry and lactating sows compared with one diet for both can reduce the excretion of N and P by 20% (Jongbloed and Henkens, 1996).

Using Amino Acids (AAs) to Replace Protein

Protein is an expensive nutrient in pig diets, so maximizing the efficiency of protein and AA utilization is important. Diets containing AAs at minimum requirement (for maximum lean growth) with minimal excesses is critical. An experiment using chemically defined diets containing AAs as a sole source of dietary nitrogen, showed that, with a near perfect AA balance, a 15 kg pig is capable of converting 87% of its absorbed nitrogen above maintenance to carcass protein. This does not mean that each of the 23 AAs found in dietary protein are used at 87% efficiency for protein (some are used more efficiently, others less). Baker and Chung (1992) proposed ideal ratios for pigs in three different weight classes (Table 5).

Table 5: Ideal AA patterns for pigs in three weight ranges (ratios are expressed on a true digestible basis)

	Ideal patterns (% of lysine)		
Amino acid	5-20 kg	20-50 kg	50-100 kg
Lysine	100	100	100
Threonine	65	67	70
Tryptophan	17	18	19
Methionine	30	30	30
Cystine	30	32	35
Methionine + cystine	60	62	65
Isoleucine	60	60	60
Valine	68	68	68
Leucine	100	100	100
Phenylalanine + tyrosine	95	95	95
Arginine	42	36	30
Histidine	32	32	32

Source: Baker, 1996

Feed ingredients are combined to meet the pig's requirements for the most limiting amino acid. As a result, the protein content of the diet is higher than required because of the presence of excess amino acids. For grower-finisher pigs, the greatest improvements in the efficiency of N utilization can be achieved from improving the dietary AA balance, so that the diet more closely reflects the true balance in which amino acids are required. Through manipulation of the dietary AA balance, N excretion in manure can be substantially reduced, by 35% in grower pigs and 20% in finisher pigs, without affecting animal performance (Tuitoek et al. 1993). In a simple example, N excretion can be decreased by approximately 15% when a 16% protein grower is replaced by a 14% protein grower at 60 kg.

Synthetic AAs are commonly added to swine diets. L-Lysine-HCL is the most commonly used, and DL-methionine is used in some diets. Recently, synthetic L-threonine and L-tryptophan have become commercially available. The ability of the swine industry to efficiently use competitively priced synthetic AAs is limited by our knowledge base of AA requirements of pigs and of biological availability of AAs in feed ingredients (Coffey, 1996). With the current cost of synthetic AAs, it does not make sense to include synthetic AAs other than lysine in grower pig diets but this will change as the availability and price of tryptophan improves (deLange, 1997).

Removal of Minerals in Late Finishing

Dietary excesses of most nutrients are common, especially during late finishing. Since these excess nutrients are excreted as waste, researchers have recently been investigating the potential for removing trace minerals in late finishing. In three separate experiments (Kim et al. 1995; Patience and Gillis, 1995; Mavromichalis, 1995), vitamins and trace minerals were removed between three and five weeks prior to market. Results conclusively showed that there was no effect on animal performance or carcass characteristics. The impact that this practice may have on nutrient levels in manure is uncertain. Regardless of the impact, it is currently illegal to remove premixes for any animal because mineral

and vitamin levels in the ration would drop below the legal minima set out in the federal Feeds Act.

| Top of Page |

Lowering N and P excretion through Genetics

Biotechnological genetic research and management technologies that will enhance the digestibility and nutrient balance of feed ingredients to meet animal nutrient requirements is vital to achieve significant reduction in nutrient outputs. Over the past 20 years, the feed efficiency of pigs growing from 25 to 110 kg has decreased from approximately 4.0 to less than 2.85 in top-producing herds. Apart from nutrition, genetics will be most the important discipline to future improvements in feed efficiency and nutrient utilization.

An improvement in the pig's production potential will result in a more efficient utilization of dietary nutrients. This can be achieved through genetic selection or the use of biotechnology. Jongbloed and Lenis (1992) estimated that N and P excretion would be reduced by approx. 15% when boars rather than barrows were used for meat production. From this it can be suggested that every 1% change in animal performance potential will result in a 1% improvement in efficiency of N and P utilization (deLange, 1996).

Researchers at the University of Guelph are currently developing a transgenic pig that will be able to produce its own phytase. When the pig is developed, it will not require additional P beyond that provided from the diet, practically eliminating the need for added calcium phosphate in the diet. Grower-finisher pigs require added P to meet nutritional requirements during growth at a cost of $1.30/pig. For the 4.6 million pigs sent to market in Ontario each year, that is a savings of $6 million. In addition there will be a coinciding improvement in the utilization of micro-minerals.

Researchers expect that these transgenic pigs will be in demand all over the world and that export of breeding stock will increase significantly in the short term as a result. Researchers estimate the total economic benefit to Ontario as a consequence of the transgenic phytase pig will be in the vicinity of $166 million/year (see Table 6), not including the expected increase in exports of processed meat products.

Table 6: Benefits of pigs containing the PHY gene

Item	*Per Pig*	*Ontario/year*
Reduced feed phosphate		
reduced capital land cost		$6.0 million
Increased national sales - breeding stock	$1.30	1. million
	2.47	2. million
Increased international sales - breeding stock	400.00	42.0 million
	600.00	90.0 million
Increased employment in swine industry		$165.9 million
Total		

| Top of Page |

Conclusions

Several options currently exist for reducing nutrient excretion on-farm:

- calculate on-farm mineral balance to develop a current snapshot of the operation
- maintain minimum requirement levels of Cu and Zn
- improve performance potential to maximize efficiency and minimize nutrient excretion
- consider the addition of enzymes such as phytase to feed
- adopt feeding strategies, such as phase feeding or the use of AAs, that will eliminate excesses and meet requirements while improving profitability

As nutrient management continues to grow as an issue in the agriculture sector, the swine industry must examine alternative methods that can substantially reduce nutrient excretion. Without steps to further reduce N and P excretion on-farm, regulations may eventually become a reality in Canada as they have in the Netherlands.

| Top of Page |

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| Top of Page |

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